1 NOVEMBER 1979

EXPERIMENTAL AUTONOMOUS VEHICLE PROGRAM

EAVE

DEVELOPMENT OF UNMANNED, UNTETHERED, SUBMERSIBLE TECHNOLOGY FOR INSPECTION TASKS

PREPARED FOR

RESEARCH AND DEVELOPMENT PROGRAM
OUTER CONTINENTAL SHELF OIL AND GAS OPERATIONS
U. S. GEOLOGICAL SURVEY

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PREFACE

This program is the development of technology for unmanned, free-swimming vehicles capable of performing inspection tasks on underwater pipelines and offshore structures. It is an attempt to be quite independent of man - hence the name Experimental Autonomous Vehicle (EAVE). The program is not vehicle-development, nor is it the optimization of the various subsystems for unmanned submersibles. Instead, it is investigation of technologies existing in the scientific and technological communities for the purpose of establishing and demonstrating new ways of performing basic underwater tasks of potential importance to the Geological Survey's offshore regulatory mission.

Whereas the Old Testament accounts for only one EAVE, there are two more: EAVE East and EAVE West. At the inception of the Program, two vehicles were already under development. At the University of New Hampshire, a free-swimmer was being devised which would use acoustics for both navigation and communications. This rather symmetrical vehicle offered high maneuverability needed around structures. The Naval Ocean Systems Center project chose a torpedo shaped configuration that was slated for optical fiber communications and for magnetometer navigation. This vehicle offered promise of higher speed operation which would be desired when navigating along underwater pipelines. In addition, its magnetometers would be able to "follow" the pipelines even though buried. A unique opportunity was therefore presented to the Geological Survey for sorting out the operational and technical parameters for free-swimmers, and, thus, the EAVE program was born.

This document summarizes these tasks as well as the organizations and methodologies for accomplishing them. Its purpose is to assist in providing an orderly progression from milestone to milestone and to record the technology. In addition, the document is used to inform others who may have an interest.

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INTRODUCTION

1.1 PURPOSE.

This program develops the technology for conducting inspections of undersea pipelines and structures by means of unmanned, free swimming submersibles. Underwater pipelines and structural inspection tasks are of direct concern to the U.S. Geological Survey's (USGS's) Research and Development Program, whose major objectives are to develop technology for pollution prevention and safety in outer continental shelf oil and gas operations.

1.2 BACKGROUND.

Underwater systems employing divers were the earliest means of inspecting objects and performing other useful work. Over the years, these systems have used nonsaturation and, for deeper structures, saturation diving techniques in which the diver's blood was either nonsaturated or saturated with dissolved gases. Saturation diving techniques have extended working depth capabilities to about 1000 feet.

Developments in one atmosphere manned submersibles for inspection and other non-military purposes began in the early 1930's, and were exemplified by the Beebe-Barton bathysphere. The usefulness of these early submersibles was limited to observations down to about 4000 feet, their occupants being protected from ambient sea pressure by heavy pressure hulls. The desire to make these vehicles competitive with divers in work effectiveness led to developments of "free-swimming" manned submersibles beginning in the early 1960's.

The evolution of these vehicles has led to two types of submersibles in current use - manned and untethered such as ALVIN, and unmanned tethered such as SCORPIO. Manned tethered vehicles have been explored and built in at least one case. All these systems require a human operator to control the vehicle, whether on board the submersible or remotely through a tether cable.

The progression of unmanned vehicle system technology from towed to untethered is shown pictorially in Figure 1-1. It is seen that the classification of these various unmanned vehicle systems is based upon the support provided by the surface craft. The towed system cable, for example, transmits mechanical power to the vehicle as well as electrical power and communications. The tethered submersible cable transmits only electrical power and communications whereas the untethered submersible only receives communication support, if required. The untethered submersible classification is therefore divided into two categories: supervisory controlled (requires communication support) and totally autonomous (no communication support required). Progression toward the use of totally autonomous vehicles reduces the requirements for surface ship support.

Figure 1-2 outlines the development of unmanned vehicle technology since 1957 and projects it to 1987. The feasibility of attaining future advances is based upon developments in electronic and computer micro-miniturization, associated software and low-power, large-scale integrated (LSI) circuits which permit use of preprogrammed electronic feedback control systems. New data coding techniques, coupled with onboard microcomputer decoding capability, have encouraged the development of acoustic and electromagnetic linkages. It is these advances which are being pursued in the Experimental Autonomous Vehicle (EAVE) program and which are described herein.

1.3 APPROACH.

The EAVE program has taken advantage of vehicle developments already begun at the Naval Ocean Systems Center (NOSC) and the University of New Hampshire (UNH). These vehicles are used as test beds to develop unmanned, untethered submersible technology. Both vehicles are open frame which prove ideal for additions and modifications. They are controlled by means of onboard microprocessors/computers which receive input from control sensors.

1.3.1 ORGANIZATION.

The opportunity to use these test bed vehicles to investigate and compare technologies for underwater inspection tasks has led to the USGS sponsorship of a joint NOSC/UNH project - EAVE. NOSC is designated as the Technical Coordinator of the project, the organization for which is shown in Figure 1-3.

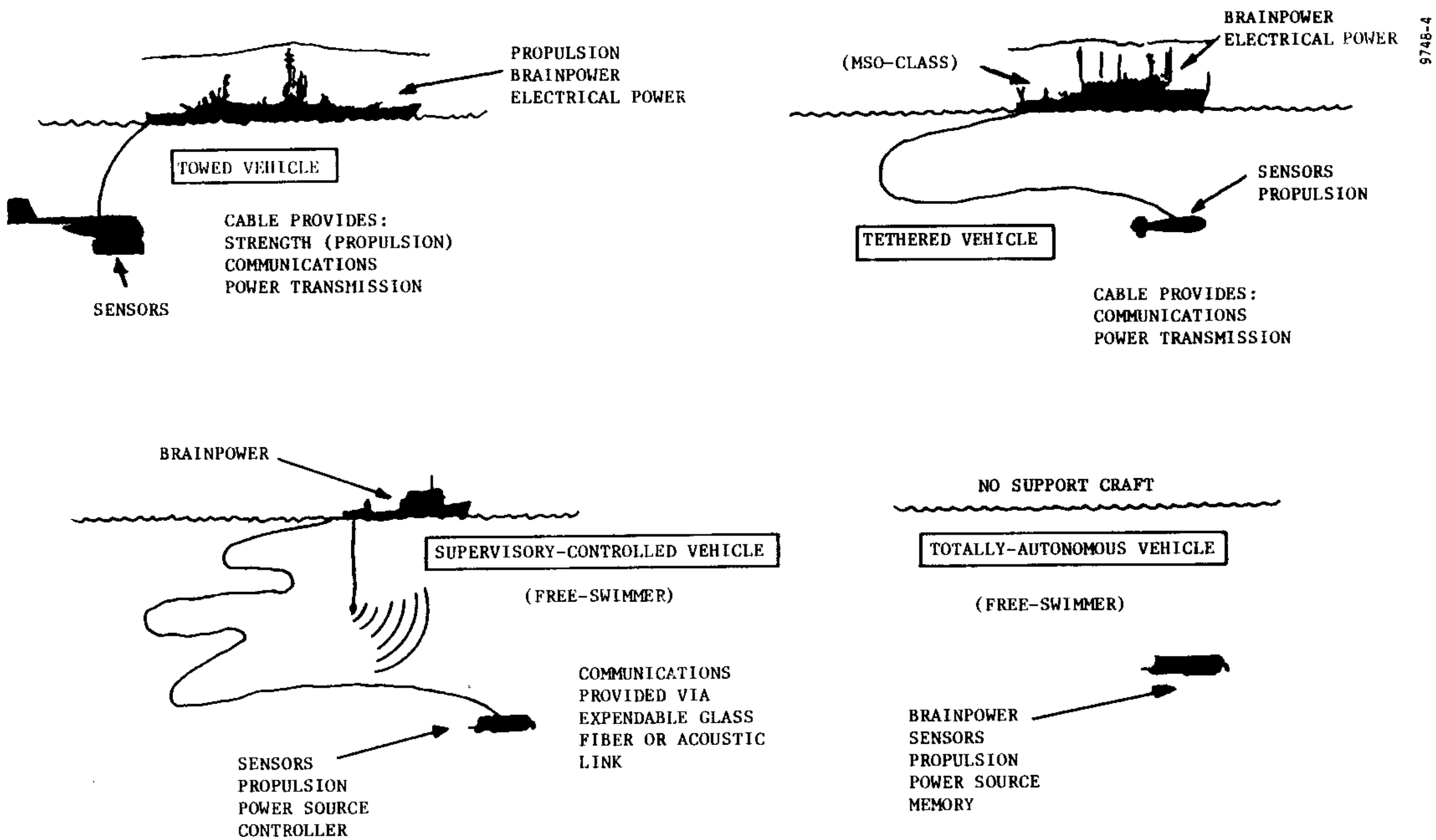

Figure 1-1. Classification of Undersea, Unmanned Vehicle Systems

Beginning of Development

SUBSYSTEM	1957 FIRST UNMANNED VEHICLE DESIGN	1967 PRESENT DAY DESIGNS	1977 FREE SWIMMER DESIGN	1987 ROBOT VEHICLES WITH ARTIFICIAL INTELLIGENCE
Electronics Design Base	All analog circuitry.	Hard wire digital with analog feedback control.	Micro-processor based digital using A/D and D/A interfaces with sensors and controls.	Distributed micro-processor architecture.
Control	Joy stick control with TV feedback.	Analog circuit feedback control loops to provide auto-hold functions.	Digital circuit feedback control to provide auto-hold functions and programmable track patterns. Automatic emergency routines.	Scene analysis. Pattern recognition. Obstacle avoidance. Onboard absolute (transponder) navigation and/or interial navigation. Adaptive control system. Self preservation.
Display Console	Special hard wire console rack.	Special hard wire consoles with sonar systems added.	Alpha-numeric CRT display and eventually a graphics display system augmented with joy stick.	Alpha-numeric and color graphics display systems augmented with joy stick.
Data Storage	None on vehicle. TV recording on surface.	Film recording on vehicle. TV recording with voice of time, etc.	Film recording on vehicle. TV frame grabbing. SLS recording	Much more data storage through bubble memories and disk recording.
Support Equipment (Required)	Support Craft. Control Console. Vehicle Handling System. Multi-conductor Cable. Cable Handling System.	Support Craft. Control Console. Vehicle Handling System. Coaxial Cable and Multiplex. Minimum Cable Handling System.	Support Craft. Control Console. Vehicle Handling System.	Same.
Sensor Systems	TV Camera.	TV Camera. Film Camera. Sonar.	TV. Film. Side-looking Sonar Magnetometer.	Additional.
Physical Task Systems		Manipulators. Drills and associated equipment.	Manipulators. Cavitation erosion cleaning.	Additional.

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Figure 1-2. Development of Unmanned Vehicle Technology

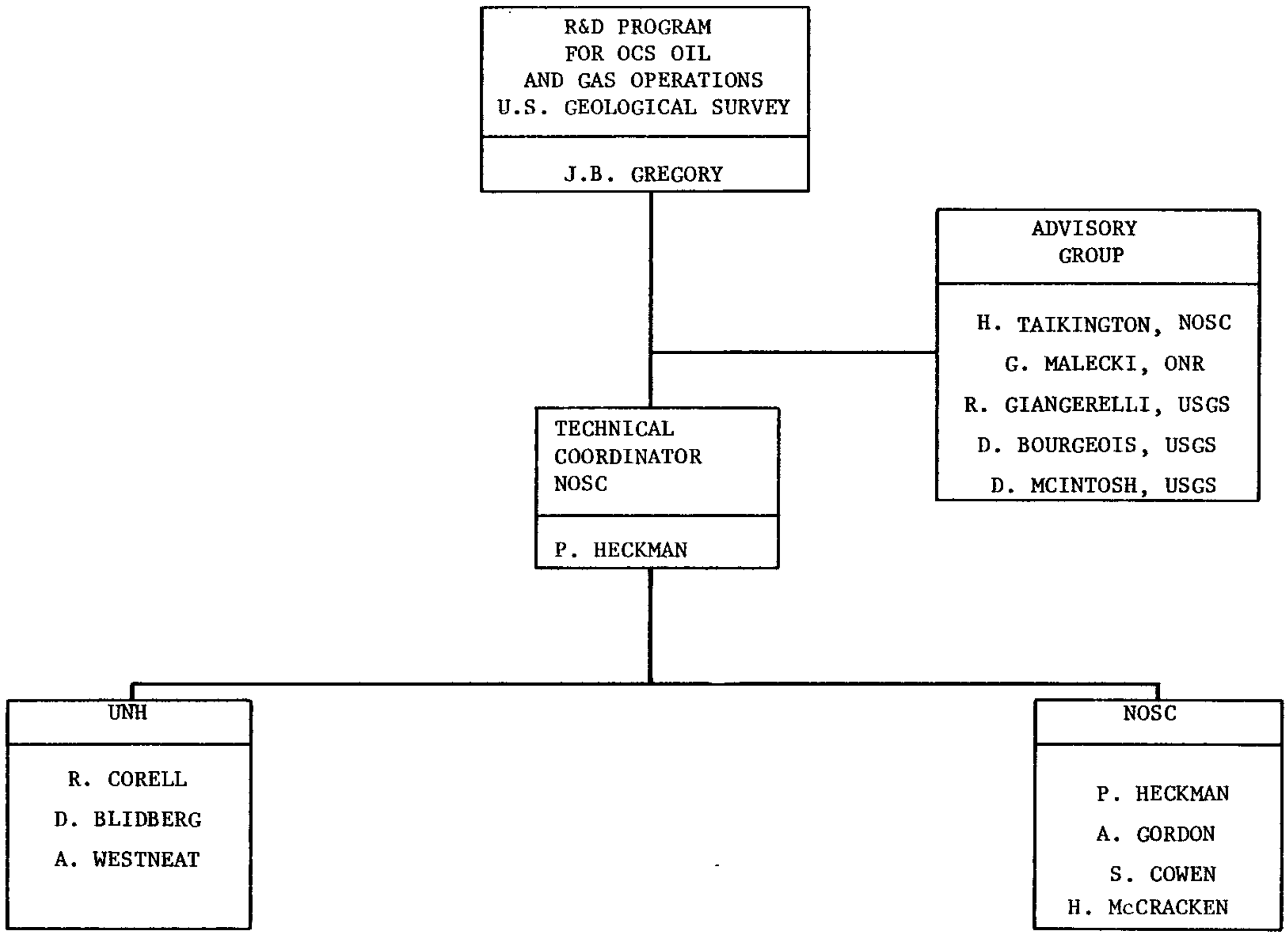


Figure 1-3. Organization Chart

1.3.2 INSPECTION TASKS AND REQUIREMENTS. Inspection tasks that have been identified are as follows:

a. to inspect pipelines under USGS jurisdiction for their geographical coordinates, oil/gas leakage and, where exposed, for signs of deteriorations in their concrete coverings.

b. to inspect the submerged portion of offshore oil and gas platforms and other structures during and after installation for defects prejudicial to structural integrity such as cracks and bent, broken or missing structural members.

Detailed inspection requirements are as follows:

a. Pipeline inspection tasks.
   (1) Conduct pre- and post-inspection mapping of areas of pipeline route to determine its geographical coordinates and pertinent terrain characteristics.
   (2) Initiate inspection by locating specified starting point on pipeline.
   (3) Navigate along, or track, pipeline with precision required by onboard sensors to perform their functions, the platform's maneuvering ability to permit stopping, maintaining position (hovering) and retracing pipeline.
   (4) Observe, by means of onboard sensors, irregularities in pipeline condition; report these irregularities to a remote station and, upon command, perform a more detailed inspection or move to a new inspection area.

b. Offshore structures inspection tasks.
   (1) Locate structure, or a particular section of total structure to be inspected, after deployment in the approximate area.
   (2) Navigate so as to trace structural member(s) being inspected with precision required by onboard sensors to perform their

functions, maneuvering ability to permit stopping, maintaining position (hovering) and retracing a structural member or network of members.

(3) Observe by means of onboard sensors, gross structural irregularities and defects; report these irregularities to a remote station and, upon command, perform a more detailed inspection or move to a new inspection area.

Performance requirements derived from the inspection tasks include:

Environmental Requirements

(1) operating areas------------------------- OCS of the United States

(2) operating depth (max)------------------- 2000 feet (near-term goal)
6000 feet (long-term goal)

(3) operating sea-state (max)--------------- as limited by support vessel

(4) current velocity at work site (max)----- 2 knots

1.3.3 INSPECTION SYSTEM. The inspection system is defined by the subsystems comprising it. The subsystem tasks are summarized below:

a. Platform. These tasks involve improvements necessary to adapt both vehicles for underwater inspection of pipeline and structures.

b. Communication Data Processing, Storage, and Retrieval. Comprehensive data must be transmitted between the platform and a remote station on a one or two-way basis at various rates. The data is comprised of platform and onboard subsystem control, as well as inspection information.

c. Navigation and Direction Control. Involves advancing navigation technologies. Precision navigation is required for the vehicles to perform area search and mapping tasks associated with pipeline inspections and to locate underwater structures. Also required is the ability to follow pipelines and the various members of a structure.

d. Data Acquisition. Focuses on the acquisition of inspection data as well as data on navigation and direction control.

e. Physical Tasks. Involves the development of tools, as contrasted with sensors, for performing useful tasks associated with inspection. For example, manipulators are used for placing of sensors on pipelines and structures.

Figure 1-4 shows the concept of technology validation by demonstrations.

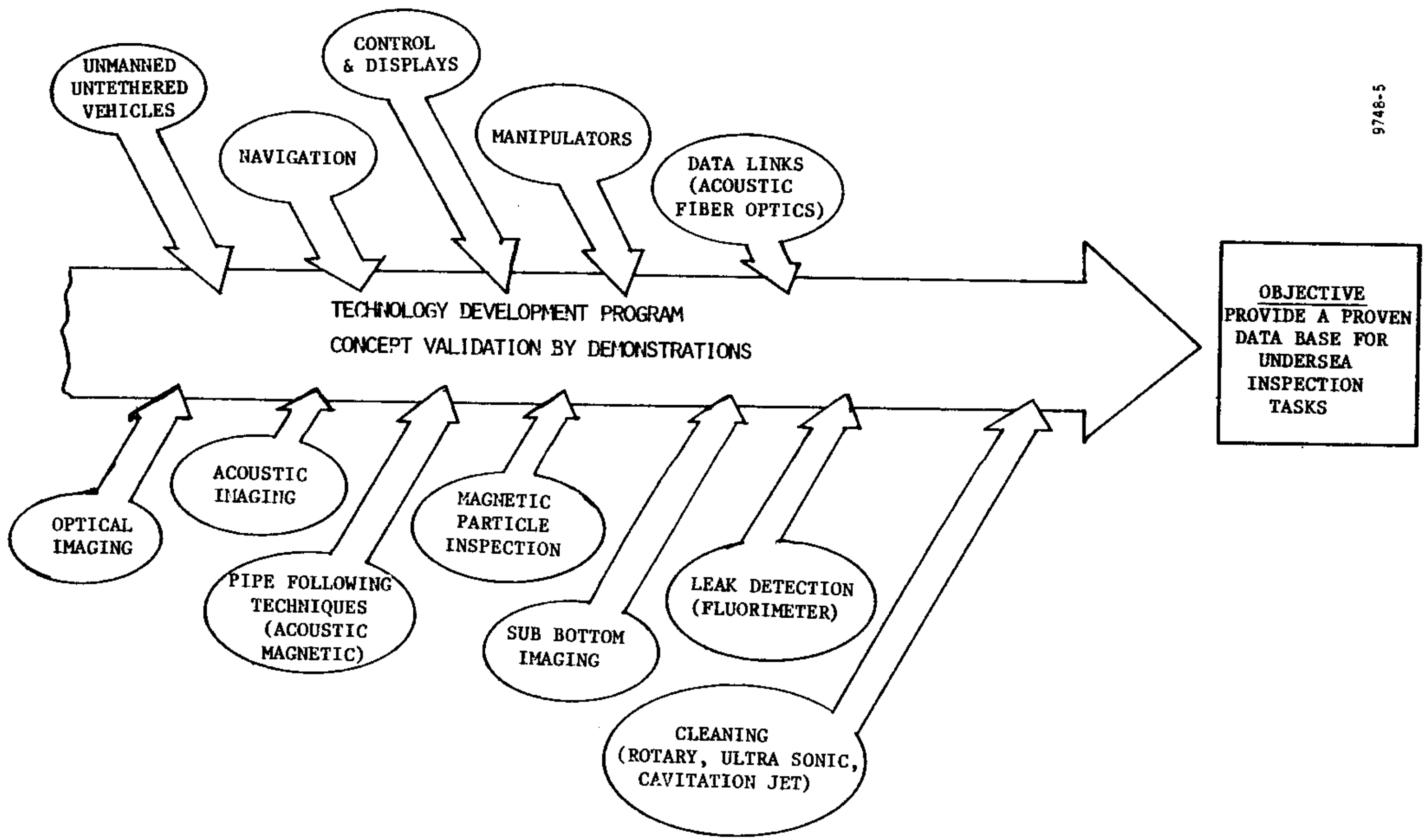


Figure 1-4. Technology Validation By Demonstrations

SECTION II

DESCRIPTION OF TECHNOLOGY DEVELOPMENT ACCOMPLISHMENTS

2.1 GENERAL.

This section summarizes technology developed on the platform subsystem; communication data processing, storage and retrieval subsystem; navigation and direction control subsystem; data acquisition subsystem; and physical tasks subsystem.

2.2 PLATFORM SUBSYSTEM.

The "torpedo" unmanned, untethered submersible has been in existence since the early days of submarine warfare, being used as a weapon employing progressively sophisticated, onboard systems control to determine its depth, course and warhead activation. In recent years, "torpedo" vehicles applicable for search and inspection missions under ice, as well as in open water, have been developed by the Applied Physics Laboratory at the University of Washington, the Department of Ocean Engineering at the Massachusetts Institute of Technology and by the Naval Research Laboratory in Washington, D.C. Acoustically controlled vehicles such as UARS (Undersea Arctic Research System) and SPURV (Self-Propelled Underwater Research Vehicle) are examples of this type.

Performance requirements of hovering and maneuvering at zero and low to medium speeds rule out the use of existing torpedoes as they are designed to have high speed, dynamical stability only with course governed by movable control surfaces. They are incapable of maintaining course at low speeds and cannot hover. A second disadvantage is that the streamlined hull of the torpedo does not lend itself to the addition of appendages such as TV cameras, side-looking sonars and other inspection sensors. Consequently, adapting "torpedo" vehicles to underwater pipeline and structure inspection missions is not feasible.

The "open-frame" type of design has been used extensively in the development of unmanned, tethered submersibles and is also being adapted to unmanned, untethered vehicles. "Open-frame" design features are exemplified in vehicles such as the U.S. Navy's family of CURV submersibles, Perry Oceanographic's RECON group and Saab-Scania's SAAB-SUB.

The "open-frame" type of submersible is ideally suited to meet the requirements of hovering and maneuvering at zero and low to medium speeds -- particularly in the absence of a requirement for high speed operation. Open-frame construction facilitates the positioning of thruster-units to obtain up to six degrees of freedom in maneuvering or to maintain position (hover) in any adverse current field. This type of construction also permits control and inspection sensors to be appended to the vehicle in the most advantageous locations for performing their functions. Sensor units can also be readily changed to provide the optimum sensor package for a given mission task.

The characteristics and capabilities of the NOSC and UNH submersibles are listed in Table 2-1.

2.2.1 EAVE WEST (NOSC). The NOSC submersible, shown in Figure 2-1 has a long narrow geometry required for zero to medium speed operations associated with underwater search and inspection missions of interest to the U.S. Navy. A schematic is shown in Figure 2-2. Its frame, presently 9 feet long, 20 inches high and 20 inches wide, has a modular construction which is readily expandable in length to accommodate additional payloads. Buoyancy for the submersible is achieved by suspending the sealed welded frame from a series of 32-pound syntactic foam blocks. The modular frame construction allows the addition of 20 to 30 pounds of equipment for each added linear foot of extension. Attached to the underside of the frame are four 7-inch diameter underwater housings containing sealed lead-acid batteries and control electronics. Also attached are data and control sensors, and three DC motor-propeller thruster units. Sensors at present include a depth sensor, a fluxgate updated gyrocompass, a silicon diode array TV camera together with a 50-watt light source, and plans for interchangeably using a side-looking sonar for pipeline search and manipulator for limited work capability. The vehicle is computer controlled using an 8080 microprocessor system located in one of the electronics bottles. At present, the vehicle is operated in a preprogrammed fashion through a supervisory control configuration using a 8080 based color-graphics control console on the surface. The vehicle is designed to follow a set of predetermined program tracks such as a straight line run, a parallel path search, or a figure eight demonstration run.

TABLE 2-1. CURRENT CHARACTERISTICS AND CAPABILITIES OF NOSC AND UNH SUBMERSIBLES

CHARACTERISTIC/CAPABILITY	NOSC - EAVE WEST	UNH - EAVE EAST
PHYSICAL CHARACTERISTIC		
LENGTH	9 FEET	5 FEET
WIDTH	20 INCHES	5 FEET
HEIGHT	20 INCHES	3 FEET
DRY WEIGHT	400 LBS	820 LBS
OPERATING CHARACTERISTICS		
SPEED (MAX SUSTAINED-STILL WATER)	5 KNOTS	3.5 KNOTS
MANEUVERABILITY	3 DEGREE FREEDOM	5 DEGREE FREEDOM
HOVERING CAPABILITY	YES	YES
REVERSE CAPABILITY	FULLY PROGRAMMABLE 3.5 KNOTS	3.5 KNOTS
MISSION DURATION	1 HOUR	4 HOURS
DEPTH (MAX OPERATING)	2000 FEET	2000 FEET
SENSORS/COMPUTER		
SENSOR SUIT		
CONTROL SENSORS	GYROCOMPASS DEPTH SENSOR LEG TIME LEAK DETECTION	TIME, ALTITUDE
DATA SENSORS	TV CAMERA & LIGHT SIDE-LOOKING SONAR MAGNETIC PIPE FOLLOWING	ACOUSTIC PIPE FOLLOWING
COMPUTER CAPABILITY		
CPU	8080A	INTERSIL 6100
ROM	20K BYTES	2K BYTES
RAM	5K BYTES	3K BYTES
WORD LENGTH	8K BITS	12 BITS
CLOCK	2 MHZ	3 MHZ
COMMUNICATIONS	PREPROGRAMMABLE	PREPROGRAMMABLE
	FIBER OPTICS	ACOUSTIC

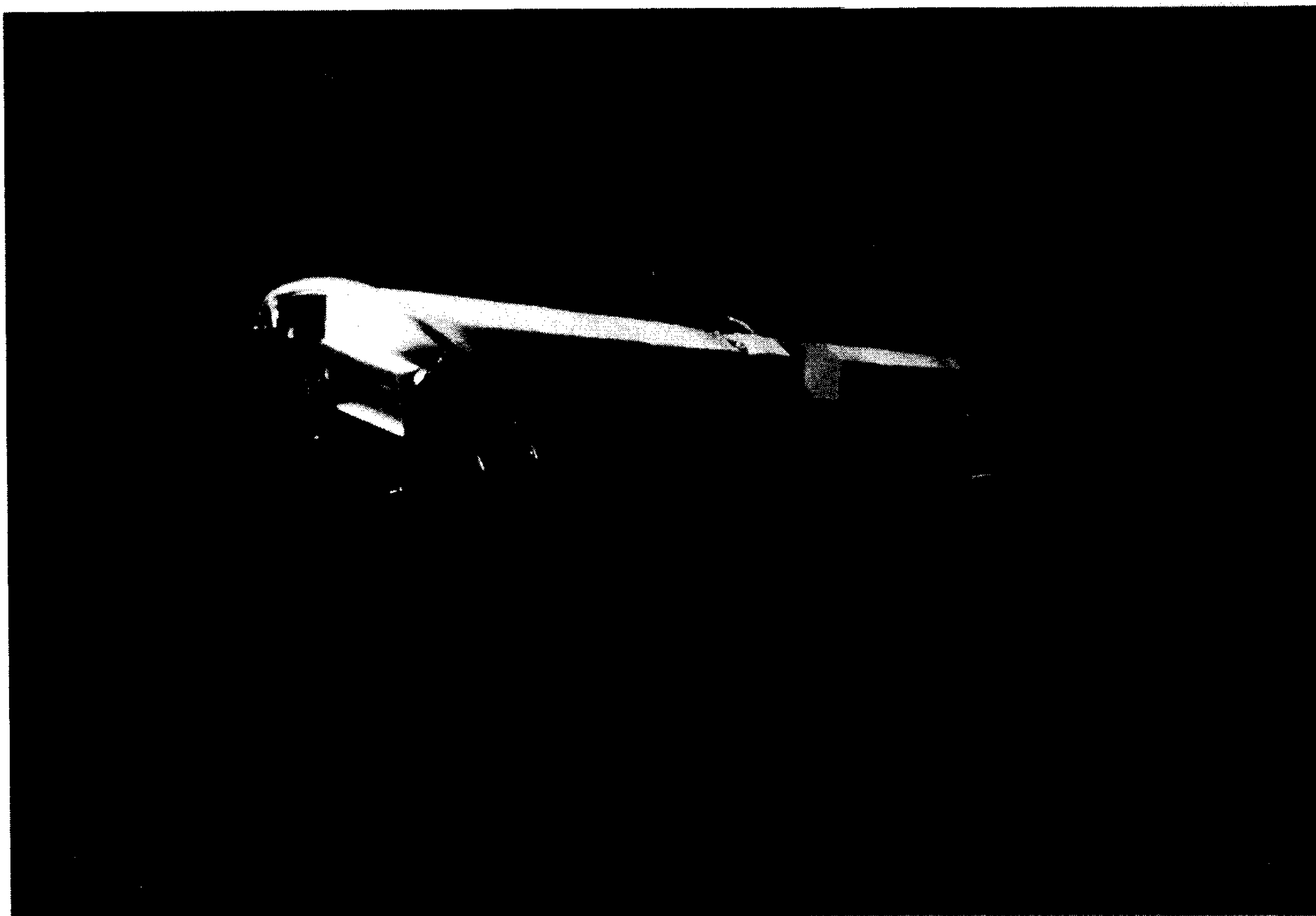


Figure 2-1 NOSC Submersible (EAVE West)

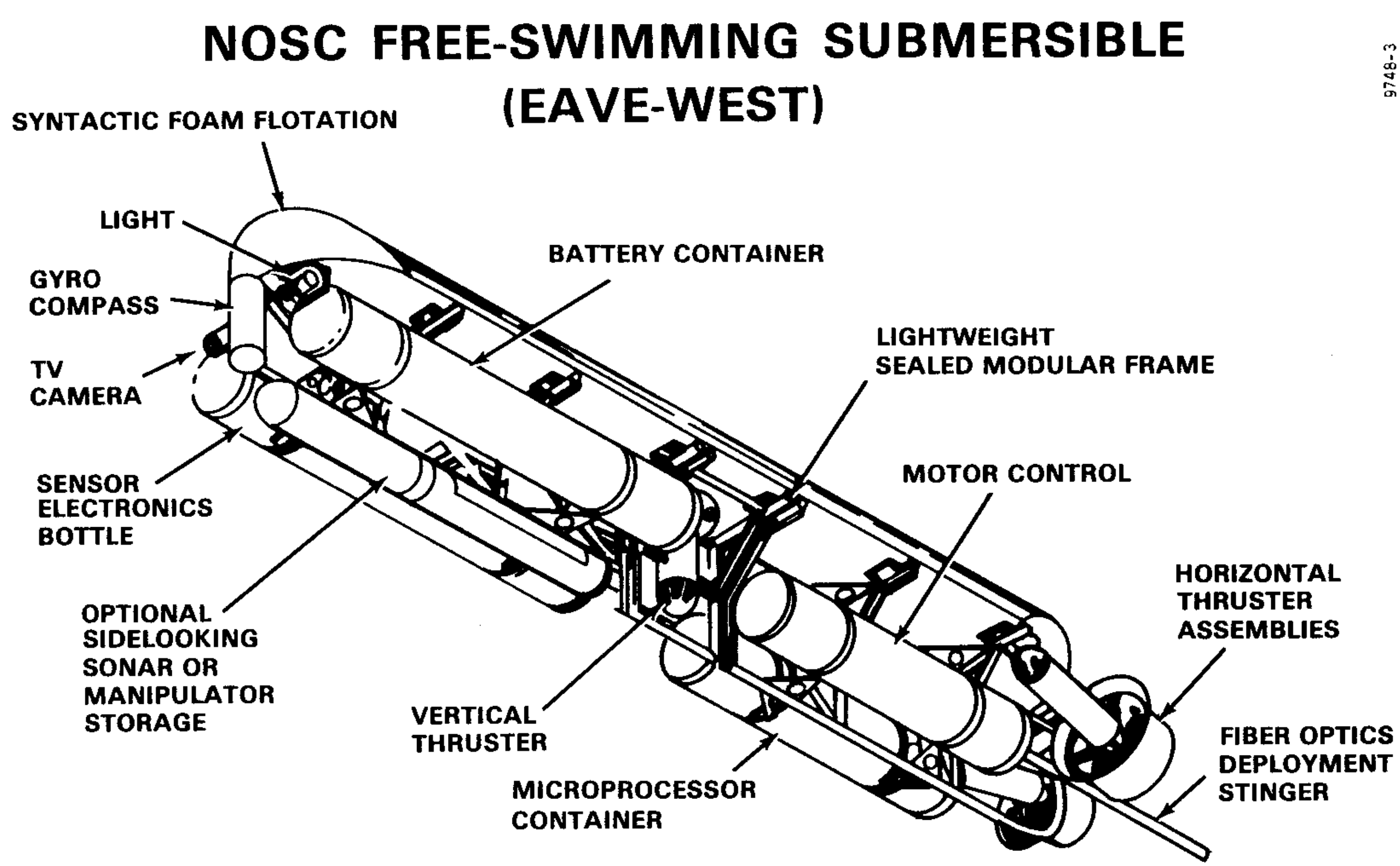


Figure 2-2 Schematic of EAVE West

In this mode of operation, the vehicle is programmed via the computer console and an umbilical cable which is disconnected after the initial pre-programming phase. The vehicle is then allowed to follow this course until its mission is completed. The microprocessor is used to compare programmed altitude, heading, depth, and run sequence input data with measured data, which in turn is obtained from an onboard altimeter, gyrocompass, depth sensor and clock, respectively. The microprocessor generates digital error signals between the programmed values and the measured values, and issues error signals to the appropriate motor controllers. The motor controllers then operate the DC motors which drive the propellers from a 24V battery supply. In the event of an emergency, a beacon is automatically activated and all thrusters are shut off so that the vehicle will surface for recovery.

After initial tests with this mode of operation, other methods of vehicle command control and communications will be demonstrated. Communications with the vehicle, while it is underwater, will eventually be made by means of a fiber optics link from the surface. Provisions are also being made for a possible acoustic link for communications. With the programmable controls used for set up of the vehicle through the hard wire link, together with some editing commands, the vehicle will then be able to (a) alter its preprogrammed mission sequence, and/or (b) respond to direct control commands from the surface.

2.2.2 <u>EAVE EAST (UNH)</u>. Figure 2-3 shows the configuration of the vehicle. Its tubular open frame is one inch diameter aluminum and provides mounting support for the battery containers, located just above the base ring; the buoyancy containers located on either side at the top; the electronics canisters positioned between the buoyancy containers; and the propeller pods.

The aluminum buoyancy containers provide 5.0 pounds positive buoyancy in the submerged-trim condition, thereby permitting the vehicle to surface in event of power failure.

The 5 foot diameter transducer ring provides a support for a navigation array which consists of twelve acoustic transducers.

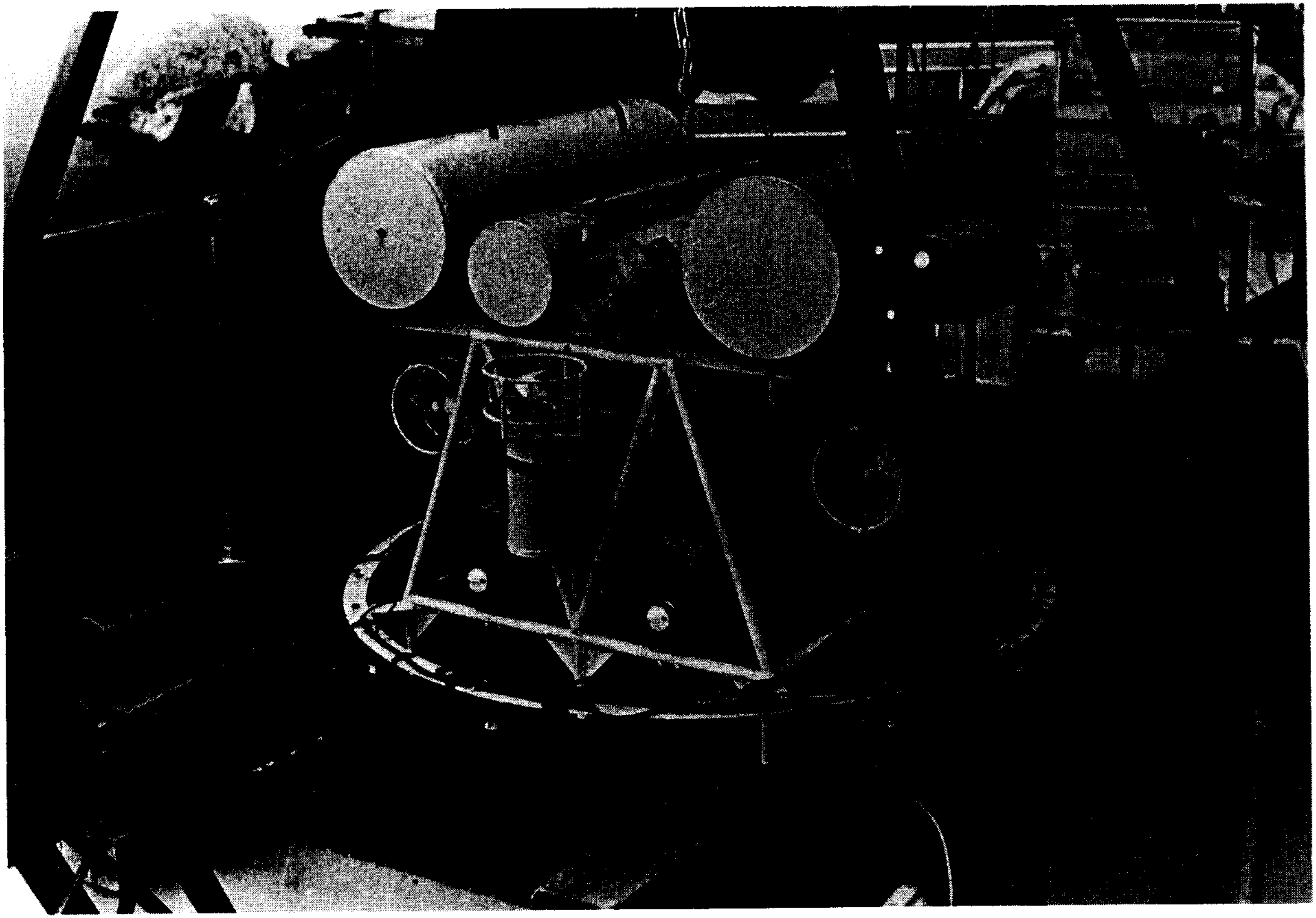


Figure 2-3 UNH Submersible (EAVE East)

The six thrusters provide 5 degrees of freedom for maneuvering, roll being excluded. Because the center of buoyancy is considerably above the center of mass, as seen in Figure 2-3, the vehicle is quite stable in roll.

The lead-acid batteries supply all electrical energy for propulsion, maneuvering, and electronic equipment. Under average conditions, a mission endurance of approximately 4 hours is attainable.

2.3 COMMUNICATION DATA PROCESSING, STORAGE AND RETRIEVAL SUBSYSTEM.

2.3.1 EAVE WEST (NOSC). NOSC efforts are directed toward the development of a fiber optic communication link and magnetic tracker. The link, over which control and inspection data are transmitted, consists of an expendable buffered (plastic coated) optical fiber similar in appearance to monofilament fishing line, through which by-directional communications are accommodated. The uplink carries a standard RS-170 television signal, a sonar channel, and a standard RS-232 computer control channel at 9600 baud. These functions are accomplished by multiplexing the 9600 baud data onto the television horizontal synchronization pulses, using Manchester code and placing the sonar channel on a subcarrier. The resulting composite signal is then modulated via Pulse Frequency Modulation (PFM) and transmitted up the optical fiber at a wavelength of 0.84 microns. The downlink carries a 9600 baud computer channel (forming a closed computer loop) which is transmitted by means of Pulse Code Modulation (PCM) at a wavelength of 1.06 microns. Color-selective duplex couplers at each end of the link separate the uplink and downlink channels, making it possible to communicate without using repeaters over a continuous length of optical fiber in excess of 10 miles.

The fiber optic link is deployed from the vehicle as it swims through the water, causing virtually no drag. Toward this end, spooling techniques are being developed which use a computer-controlled machine to wind the optical fiber onto deployment spools. Precision and repeatability are overriding concerns because errors can result in fiber breakage during deployment. A binding agent holds the spirally wrapped matrix of fibers together and controls the deployment pull-out force to about one ounce. All winding parameters are software programmable, resulting in development flexibility. In addition, the dynamics of the fiber catenary have been modeled and optimized for various currents, vehicle speeds, and depths. The fiber is a commercially available ITT buffered optical fiber which costs 30 cents per foot but which is projected to decrease in about 5 years to 10 cents per foot.

2.3.2 EAVE EAST (UNH). For the UNH test bed, the communications and navigation system make use of three dedicated microcomputers as illustrated in Figure 2-4. Each computer performs specific tasks, but communicates with the other two when necessary through a serial interface port.

The acoustic link computer system performs two major tasks: it controls the acoustic link, including both encoding and decoding of data according to a predetermined priority structure. Secondly, it coordinates communications between the three computer systems.

An acoustic communication link has been fabricated which allows data communications between a remote operator and the vehicle computer system. Using this link, the vehicle reports its status to the operator and allows him to intervene, or change its instructions. The system employs a transmission scheme which uses nine frequencies centered on 28 kHz. These frequencies are pulsed sequentially, a transmitted frequency being zero and silence representing one. The receiver then receives and decodes this 9-bit data word. The data, which is to be received or transmitted, are of three types and are encoded by one of three methods. The first type of data consists of control instructions and is of high priority. It is transmitted by the operator and received by the vehicle. The received data are then retransmitted by the vehicle to the operator so his computer can verify that the data word is the same as that sent. This method is called "hand-shaking". The second type of data are status information and are of middle priority. This information is transmitted after being encoded according to an error correction and detection algorithm (Hamming code). The received data are decoded by the receiver using the same algorithm. The third type of data are of lowest priority and are transmitted and received directly without any coding or decoding.

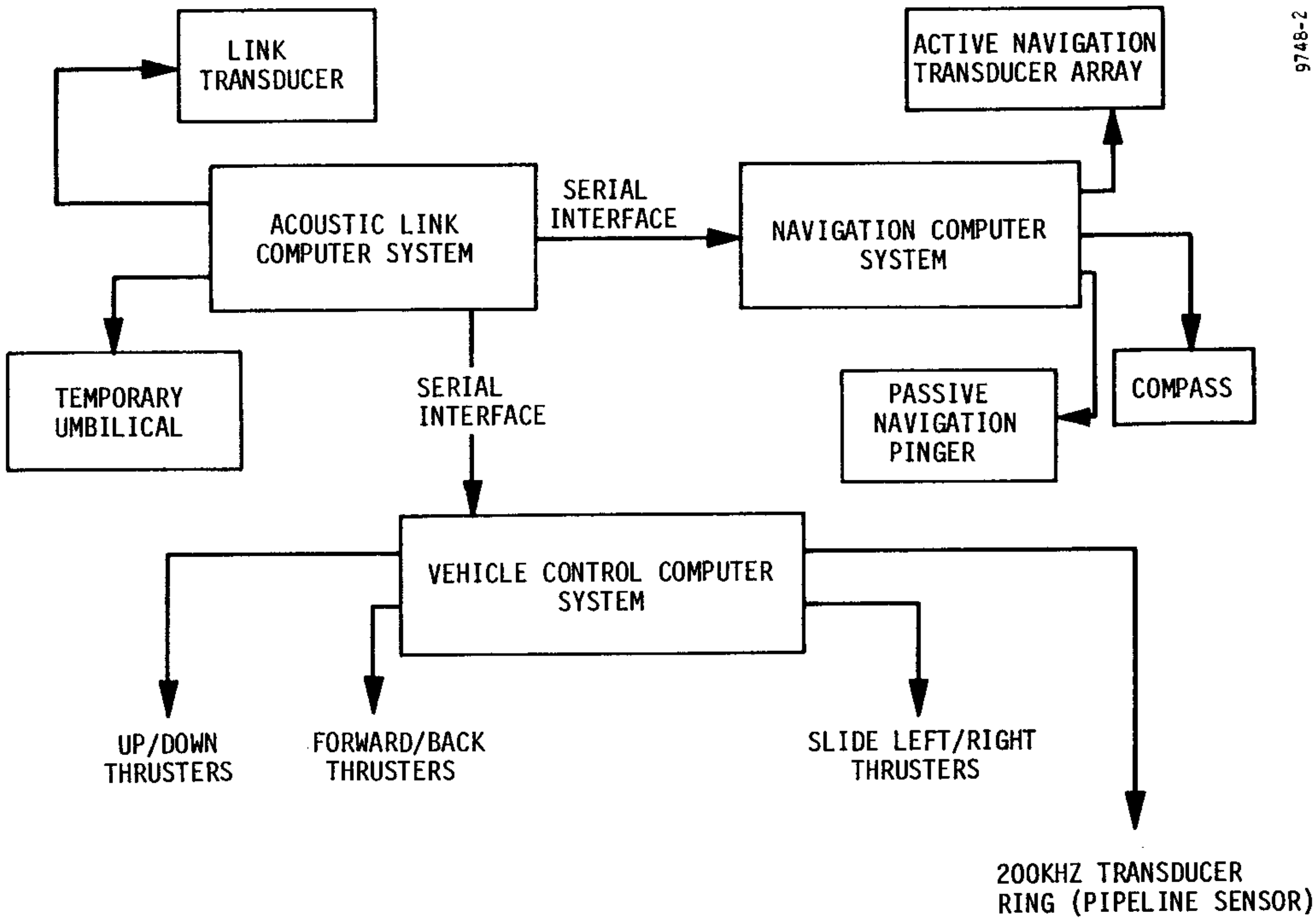


Figure 2-4 UNH Test Bed Navigation, Control and Communications Diagram (EAVE East)

2.4 NAVIGATION AND DIRECTION CONTROL SUBSYSTEM.

2.4.1 EAVE WEST (NOSC). For the NOSC test bed, both active and passive magnetic techniques have been examined for providing control information for pipeline navigation of free swimmer. Magnetic sensors were chosen for study because of their prospects for following buried pipelines. Results indicate that active magnetic systems should be pursued, primarily because of their inherently cleaner control signals. Transmitter-receiver systems operating at frequencies near either 40 Hz or 4 kHz were recommended. Intermediate frequencies should be avoided because of possible cancellation of magnetic and eddy current effects. As a result of laboratory testing, detection ranges of about 10 feet are estimated for 2-foot diameter pipelines.

A topside color graphics console and microprocessor, having 64,000 words of memory has been integrated into the free-swimming submersible system to allow operation of the vehicle by supervisory control. This mode allows quick interaction, through a computer interface, between an operator and his controls and displays. Simultaneously, the motors and actuators of the vehicle are controlled by a separate onboard computer. The two computer systems communicate through the fiber optic low bandwidth data and control link. The resulting hardware implementation of this supervisory control concept is illustrated in Figure 2-5. The configuration uses two software programs, one for interface and the other for the color graphics surface console computer system. Its use allows a reduction from 12K bytes to 7K bytes of the software which is incorporated in Programmable Read Only Memory (PROM) in the vehicle. Having this reduction, it has been possible to expand to 16K bytes the topside console program for operator interaction and vehicle tracking. The system is now readily adaptable to either fiber optic or acoustic control by using standard RS 232 format up to a rate of 9600 baud. Provision has been made to change the baud rate from the console keyboards and adapt to any given communication channel at a moment's notice, which is particularly useful when acoustically controlling a free-swimming submersible.

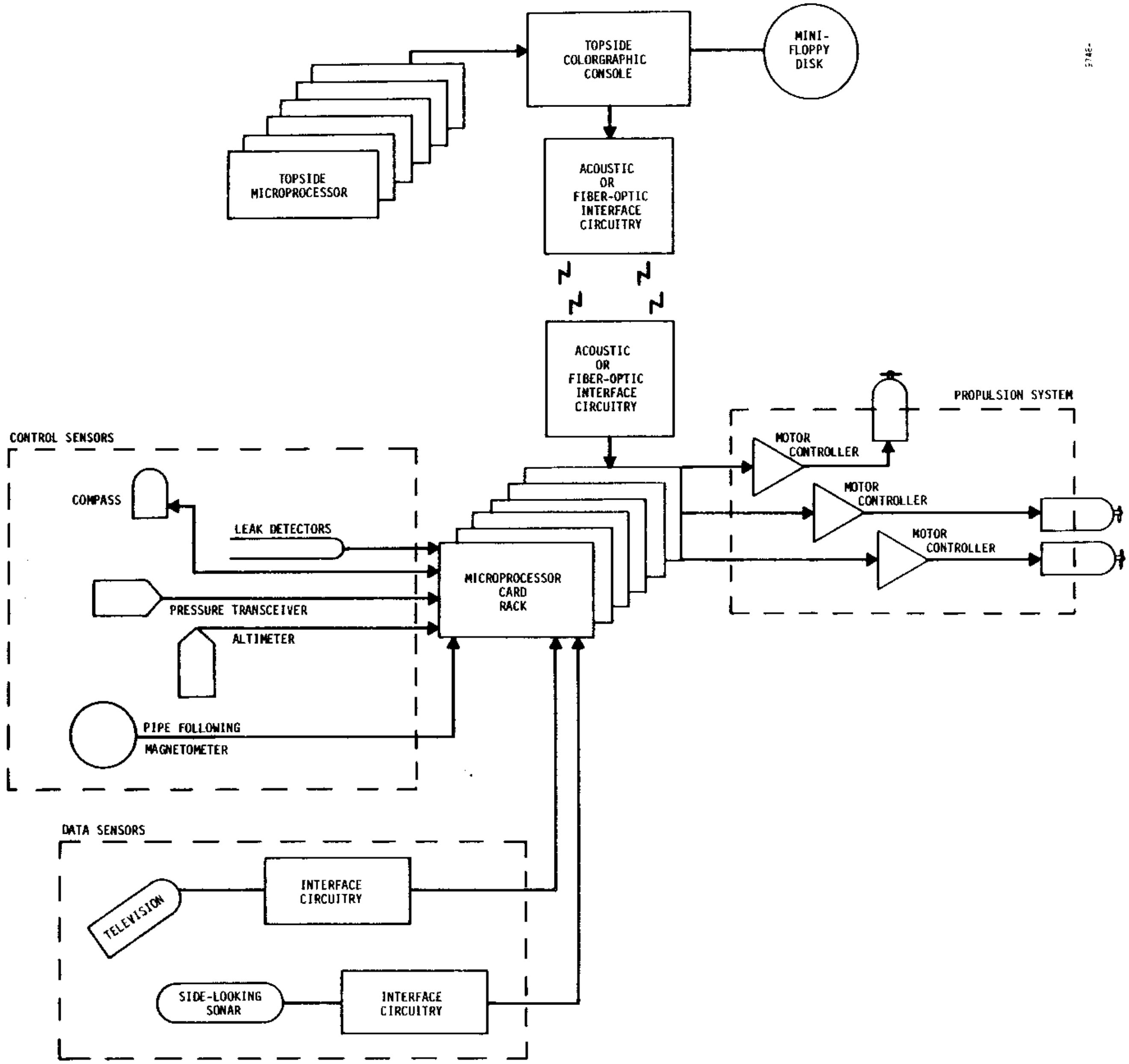


Figure 2-5 Supervisory Control Concept for the NOSC Free Swimming Vehicle (EAVE West)

2.4.2 EAVE EAST (UNH). The control computer system is responsible for vehicle movement. It controls the vehicle's six thrusters in accordance with programmed instructions or by information received from navigation sensors.

The navigation computer system computes the vehicle's position and provides that information to the other computer systems. Two navigation systems are being investigated. One is a high resolution system which will be used for precise movement within a designated work area. A second navigation system under development is for homing; it uses a range and bearing scheme for navigating to and from a given area.

In the development of the vehicle, it is necessary to track its position with respect to a pipeline, for example, as well as to geodetic reference points on the test range. A short range system has been developed which uses an active beacon on the vehicle and three receiving hydrophones at known positions on the floor of the test range. The vehicle carries a precision crystal clock which is synchronized with a similar clock at the operator's control console. Once this common time base is established, the arrival of a transmitted pulse at each of the three sensors permits computation of the ranges from them to the vehicle. A microprocessor computer then calculates the vehicle's position, converts the data to cartesian coordinates, and displays the position for the use of the operator.

Though the navigation system is designed to measure vehicle performance, it is also applicable for short range, precision navigation. In this case, the three fixed hydrophones are used in the active mode and transmit simultaneous pulses which are received aboard the vehicle. The navigation computer, now carried by the vehicle, calculates its position so that the vehicle may proceed on any software-defined program which is referenced geographically.

This navigation system is of limited use because it can only determine the vehicle's position and can not sense its way along a pipeline or structure. It is necessary, however, to use it at such times as post-launch and prerecovery.

Another navigation system, a tracking system, is under development. In this concept the vehicle carries a horizontal acoustic receiving array consisting of three hydrophones displaced by a total phase angle of less than 180 degrees. A pulse from a remote transmitter is received at each phone at incremental times, which, together with elapsed time, measured by synchronous clocks at the transmitter and vehicle, permit determination of bearing and range. Digital circuitry converts the phase differences between each of the three received signals into 12-bit words. The data then are processed into cartesian coordinates by a microprocessor-based computer using the output of a compass and a range measurement.

The navigation system computer uses a 6100 microprocessor with 3K (3072 bytes) of 12-bit Random Access Memory (RAM) plus 1K of Ready Only Memory (ROM), which contains the system software.

Vehicle position errors are related to its range from the beacon. A bearing error of 5 degrees is expected and total range errors appear to be about 3 yards at 100 yards. The combined effect of these errors produces a position displacement which is a function of range. In the transiting or homing mode, the error decreases with range, permitting a greatly improved probability of the vehicle reaching the work area, or on return, meeting the recovery vessel.

2.5 DATA ACQUISITION SUBSYSTEM.

2.5.1 OPTICAL IMAGING. One of the most important and widely used methods of inspection of both underwater pipelines and structures is visual or optical imaging. Although the technology for placing and operating still or motion picture cameras on free-swimming submersibles is readily available, the use of real-time optical systems such as TV cameras for use in operator controlled or supervisory controlled operations needs further development. In particular, problems of providing an inexpensive and reliable means of meeting bandwidth requirements are to be investigated in the near future. A slow-scan television system incorporating free grabbing electronics and a means of storing a 255 x 255 x 4 bit picture element in Random Access Memory (RAM) will be developed and evaluated on EAVE West. Various bandwidths and transmission rates will be investigated. Previous experiments performed under NOSC independent exploratory development funding indicated reliable acoustic transmission of 128 x 123 x 4 television pictures at intervals of 8 seconds/picture were possible in depths of 4,000 feet. An onboard acoustically transmitted television system will be designed and fabricated. The television system and light are on hand and will be available for comparative pictures transmitted by fiber optics link.

2.5.2 ACOUSTIC IMAGING AND SIDE-LOOKING SONAR. There are basically three types of acoustic imaging systems that could be used underwater for inspecting pipelines or structures. These are photographic or acoustic lens style systems, holographic systems, and side-looking sonar systems. Of the three, the most widely used inspection system in the off-shore community is the side-looking sonar. This approach to taking acoustic "pictures" underwater is so well developed that in many cases the resolution of the sensor is higher than the ability of the platform to remain steady under power. In most cases, systems with a one degree base are not only adequate for pipeline inspection tasks but are quite inexpensive (i.e., on the order of $20,000 for the entire sensor and recorder system). Such systems can be easily used with tethered or towed unmanned submersibles wherein the cable is used to transmit the data from the sensor to the topside console and associated recording electronics. What has not been developed is the ability to use such sensors on free-swimming submersibles where the problem of recording on-site the side-looking sonar data or transmitting the data back to the surface support ship acoustically. In addition, work is yet to be done to automatically decipher the side-looking sonar data for such targets as pipelines.

2.5.3 PATTERN RECOGNITION AND SCENE ANALYSIS. As the development of free-swimming submersible technology approaches the goal of total autonomous information must not only be gathered, but must be reduced onboard for decision making. In particular, it is important to be able to distill the vast amount of information taken with TV cameras and side-looking sonar sensors in order to discern sizes, shapes, and relative locations of objects. As the functions of the human operator are eliminated, processing systems will have to supply to a decision making brain on board the vehicle information obtained from the same types of sensors.

Technologies such as scene analysis and pattern recognition have been developed in the artificial intelligence and aerospace fields in the recent past. Application of these more theoretical areas of technology to the hard, real world of underwater vehicle design should produce a relatively great reward for minimal cost. Specifically, the application of scene analysis of underwater TV pictures should provide a real-time means of optically navigating along a pipeline or structure without the addition of a complex array of optical sensors. The same type of technology should allow the vehicle to recognize problem areas such as a missing or broken brace on a structure, and then to automatically take documentary or corrective action without the need for constant human interaction.

2.6 PHYSICAL TASKS SUBSYSTEM.

These tasks will be accomplished by means of a cavitation-erosion cleaning device and by a manipulator arm.

2.6.1 CAVITATION-EROSION CLEANING OF JOINTS. Under contract to the R&D Program for OCS Oil and Gas Operations, Daedalean Associates, Inc., has developed a cavitation erosion technique for cleaning underwater structural joints prior to inspection. Their technical report on the project as well as a film documentary are in preparation. A summary of the work appears in the annual technical report of the above-mentioned research program.

The parameters established for a diver-held device are as follows:

Weight of device (gun) in air	5 lbs
Flow rate	2.3 GPM
Calculated power	13.7 HP
Orifice diameter	0.031 in.
Orifice velocity	1200 feet per second
Nozzle reaction (estimated in air)	7 lbs
Nozzle reaction (estimated in water)	nil?
Cleaning rate to bright metal (6-year marine growth, using fan shaped nozzle)	1 square foot per minute
Nozzle stand-off distance (optimum)	1/2-3/4 in.

Selected welded joints of various configurations will be cleaned to bright metal. Performance data for the cavitation cleaning subsystem will be obtained and its effect will be observed upon the subsystems of the vehicle.

2.6.2 MANIPULATOR ARM. An underwater manipulator arm and its attendant subsystems are being developed by the Naval Ocean Systems Center for specific evaluation in the EAVE program. The following potential physical tasks are envisioned;

(1) Positioning the cavitation erosion cleaning nozzle.
(2) Placing a self-contained sensor package at selected positions on a structure. These packages may be attached either mechanically or magnetically.
(3) Positioning of imaging subsystems to allow visual inspection of welded joints and structural members. Candidates include still and motion picture photography, and conventional and solid state TV.
(4) Attaching a line onto instrument packages or navigation transponders through a hook arrangement to recover such packages from underwater structures or in the vicinity of pipelines on the ocean bottom.

An underwater supervisory controlled manipulator has been designed under NOSC independent exploratory development funds to provide a means of performing such tasks underwater on unmanned, untethered submersibles. The system was designed specifically for operation on the NOSC free-swimming submersible test bed to provide shoulder rotation, shoulder pivot, elbow pivot, wrist rotation, wrist pivot and hand grasp. The manipulator is capable of lifting 25 pounds at the shoulder and 8 pounds at full wrist extension. A 24 volt power supply is used for the all electric motor design. A 16-bit microprocessor system controls position feedback for the manipulator arm. The arm is fabricated of fiberglass, filled with 32 pound per sq. ft. syntactic foam. The system was designed to be lightweight and compact and yet have the capability of handling reasonably heavy loads with versatility. The system is being fabricated and will be used shortly in experiments jointly conducted by NOSC and MIT personnel, the latter sponsored by the Engineering Psychology Program, ONR. Supervisory controlled manipulation will be demonstrated through small bandwith commands originating from a console located on a support craft. As a part of this joint effort, MIT has performed a systems analysis of the current NOSC manipulator's theoretical capability (Reference 1).

SECTION III
MAJOR MILESTONES FOR TECHNOLOGY DEVELOPMENT

3.1 GENERAL.

As previously stated, the EAVE Program is technology development and demonstration wherein each subsystem is tested and demonstrated aboard one or both free-swimming vehicle platforms, EAVE East or EAVE West. Whereas the Naval Ocean Systems Center (NOSC) will, for example, be concentrating on fiber optic communication links and magnetic navigation technology, the University of New Hampshire will be investigating acoustics for both communications and navigation. The inter-relationship of each of these technological developments is shown in the interdependency network of Figure 3-1.

The sequence of research and development is to first produce appropriate testbeds for demonstrating the important technologies necessary for constructing and operating free-swimming vehicles. Next, those areas of primary importance to an inspection vehicle (e.g., the ability to follow a pipeline) will be pursued. Later, will be the incorporation of data sensors which provide operational and inspection information to an operator. Lastly, interaction with the operator is then reduced through technologies which allow processing of control information from data sensors into a useable form (e.g., the uses of scene analysis of TV or side-looking sonar to locate and track pipelines or structure elements). Thus, at this point, autonomous vehicle technologies will be attained. It is anticipated that the objectives of the program will be attained by 1983.

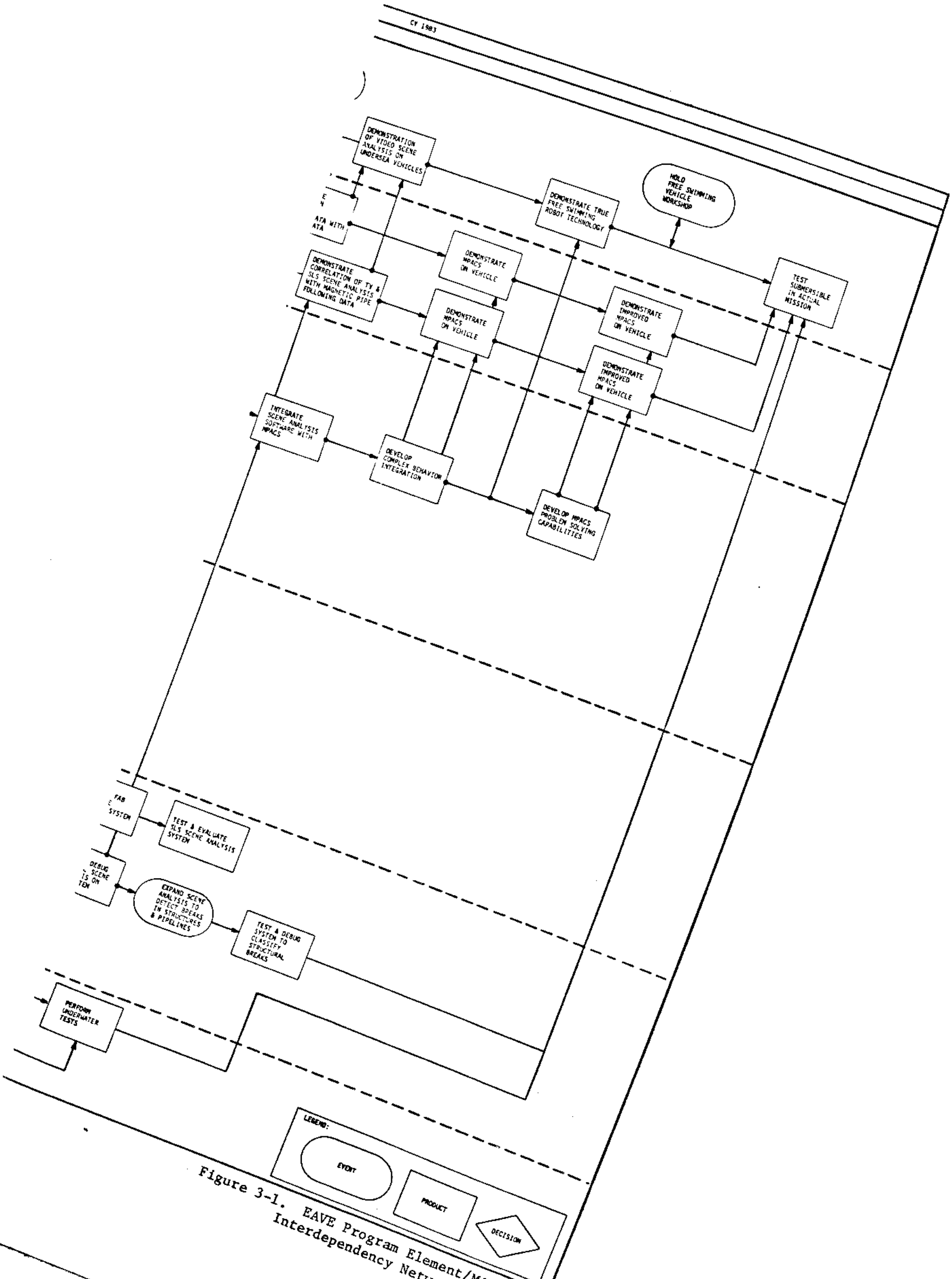
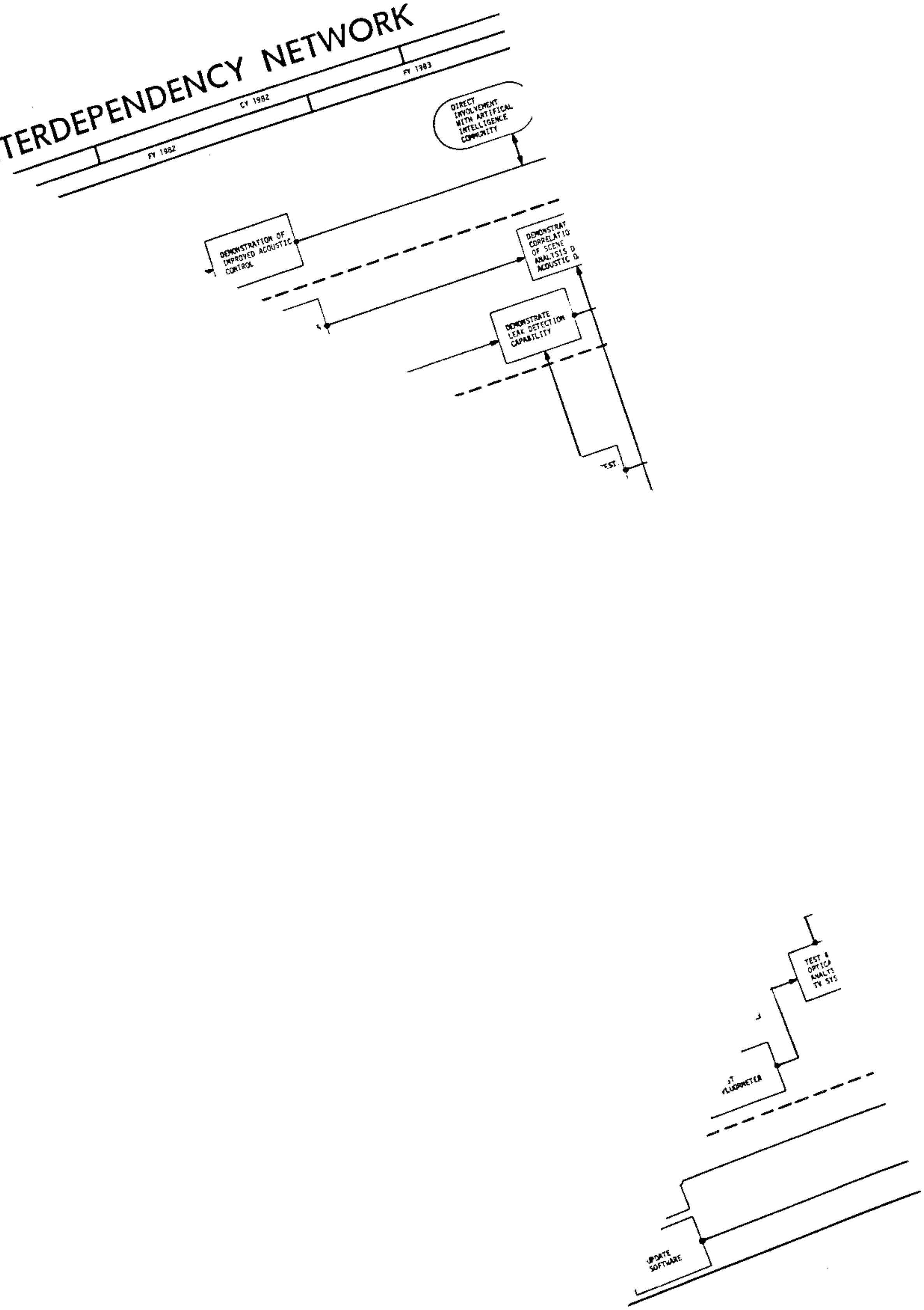


Figure 3-1. EAVE Program Element/Milestone Interdependency Network

INTERDEPENDENCY NETWORK



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